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COPY NO. 28

ANEMOMETER READOUT DESIGN

by

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and

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Quarterly Report for
January 1, 1954 through March 31, 1954

Contract No. DA-04-495-Ord-352
Sub-RAD Order No. ORDTU 2-1106-7
Ordnance Project No. TU2-1012

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Abstract

Within this report are statements concerning the present scope of work for this contract. Also discussed are the so-called electronic readout devices considered during the period of this report, for the present anemometer which has been developed under this contract.

Introduction

This report covers the work performed under Contract DA-04-495-Ord-352, during the period running from 1 January through 30 March 1954. While the program during earlier periods had been directed to the completion of a prototype wind correction computer for incorporation into the fire control system of LOKI during initial tests at White Sands, the scope of the work and its emphasis were changed near the beginning of this period by the reassignment of the computer development effort to the Bell Telephone Laboratories. Although this redirection of aims has yet to be confirmed in a written directive, we have been guided by the following verbal directives:

1. Completion of a prototype computer for incorporation in the White Sands program is no longer a requirement. The wind correction computer, which was nearing completion, is to be finished in such form as may contribute to
   a. the further development and improvement of the anemometers as fire control components, and
   b. the experimental investigation of wind characteristics of LOKI operational interests.
2. Because no other wind correction computer was in existence or might be made available within a period of several years, the LOKI tests falling within this interval, there remained a likelihood that

the developed computer and similar equipments utilizing the same or similar components and techniques might yet serve at White Sands in connection with tests of the LOKI fire control system. In particular, it seemed highly probable that some form of read-out equipment for the North American Instruments, Inc. anemometers would prove desirable during the course of the LOKI firing program.

While none of these requirements have been affirmed in writing during the past months, our estimate of the probable role of both the original wind correction computer and of simpler velocity readout equipment has been sustained both in the discussions with the sponsor, which occurred about the first of the year, and in several subsequent conferences. For this reason we have continued the effort necessary to complete the original computer design, although on a greatly reduced scale of effort consistent with the decreased urgency, and we have devoted a greater part of the effort expended on this contract on the development of circuits and techniques suitable for use in the conversion of drag components to wind velocity components as necessitated by the present anemometer design. With the exception of some modifications of the original wind correction computer, for the purpose of improving the compatibility of the wind correction computer with the existing M-33 fire control director, the effort during the past quarter has been devoted almost entirely to the development of the so-called readout equipment. The remainder of this report discusses these developments.

The Readout Problem

Because the anemometers developed by North American Instruments, Inc. for use in connection with LOKI measure drag forces along two orthogonal directions, the electrical signals produced by the anemometers are in reality the drag components $1/2\, \rho V^2 \sin \Theta$ and $1/2\, \rho V^2 \cos \Theta$, Θ being the angle of the wind vector to the principle axis of the anemometer. To obtain the desired wind velocity components, proportional to $V \sin \Theta$ and $V \cos \Theta$ respectively, it is insufficient merely to subject each of the signal magnitudes independently to a non-linear transformation. Instead it is necessary, in effect, to determine the magnitude of the drag vector, to obtain the magnitude of the wind velocity vector by taking the square root of the drag, and then to resolve this velocity vector into components in the same ratio in which the drag vector resolution occurred. Fortunately, it is equivalent if one, having determined the velocity magnitude, merely divides each of the drag components by the velocity. Thus, the readout problem boils down to three functional operations:

1. Obtain the magnitude of the drag vector, proportional to V^2
2. Square root the drag vector to obtain the velocity vector (disregarding multiplicative constants)
3. Divide each of the drag components by the resulting velocity magnitude.

The one remaining detail concerns the manner in which we take the square root. It is a relatively straightforward matter to take a square root electrically by using a non-linear impedance typified by Thyrite elements or networks suitable synthesized of diodes; we have discussed the design and performance of such non-linear square rooters in earlier reports. While such devices are suitable for low accuracy applications, they are not capable of significant improvement in fulfillment of more strict accuracy requirements. In meeting more stringent requirements, one naturally turns to operating principles in which the mathematical result stems logically from the schematic arrangement rather than from detailed component characteristics. Along this line, the simplest approach to a precision square rooter appears to involve the use of two multipliers operating in a closed loop in such a way as to reduce the input signal to a constant as a result of two successive multiplications by the same factor. It will be evident that if such a system does operate to fulfill its requirement of constant output, regardless of magnitude of input, the multiplicative factor characterizing each of the multipliers is inversely proportional to the square root of the input signal. Further, it will be apparent that the signal appearing at the mid-point between the two multipliers is the desired square root quantity. Our discussion has assumed that the two multipliers can be controlled either electrically or mechanically (as for a potentiometer) under conditions guaranteeing equal multiplicative factors at all times; herein lies the real problem in the instrumental development of the readout equipment.

As set forth in earlier quarterly reports and as a result of the reasoning related above, the development of readout circuits for the North American Instruments, Inc. anemometers involves two phases of design. First, we must develop electronic multipliers satisfying the important requirement of gain equality and, second, we must incorporate these multipliers with phase quadrature networks in such a way as to effect the desired constancy of output independent of input signal. The latter problem is one involving the design of an unusual type of servo loop, and the problem was solved quite satisfactorily in the original wind correction computer; however, the computer used servoed ganged potentiometers in the role of controlled multipliers, thus avoiding the problem of development of electronic multipliers. We have persisted in our efforts to design fully electronic multipliers of precision equalling that of potentiometers because we feel it highly desirable to eliminate the electromechanical servo components from the readout equipment, for reasons of size, weight, expense, and ease of maintenance.

Multiplier Development

During the period covered by this report, we investigated three and tried two different design principles for the construction of multipliers of high fidelity. These techniques proved unsuitable for our uses. Toward the end of this period, we adopted yet another scheme on which to base another multiplier design and the breadboard forms of this new design have given satisfactory multiplier performance. For this reason we believe that our newest design, based upon pulse-length modulation, is providing the desired solution to the multiplier problem. The discussions which follow have, therefore, a somewhat historical character but they are nonetheless descriptive of work performed on this contract.

The design principles that were investigated emphasize simplicity and equality between the several amplifiers comprising the resolving equipment. We first tried a multiplier based upon so-called RF tracer techniques. In this type of amplifier the input grid receives both the 3,000-cycle signal to be modulated and a standard signal at several hundred kc. These two component signals are subjected in principle to the same amplification and are then separated in the plate circuit of the amplifier by employing a suitably tuned RF transformer. The resulting RF signal is amplified and compared with a control signal, which is intended to determine the multiplication factor of the device. The error voltage resulting from this comparison is further amplified and applied to either the control grid or to the pentode suppressor grid in an appropriate sense to accomplish gain degeneration. The signal frequencies used in our circuit were 3,000-cycles and 455 kc. per second. This large difference in frequency made the separation of the tracer from the signal easy, but it was found that the gain characteristics of the amplifier for the two frequencies varied greatly as the control voltage was changed. Further, these variations were far from similar for differnet amplifier units. To reduce the tracer within an octave of the signal was considered undesirable because of the size and complexity of the filter units which would be required for separating signals so closely situated in frequency. The use of high frequencies for the signal would have required further operations of rectification and modulation which were considered undesirable.

The second method tried attempted to reduce the importance of the characteristics of individual tubes by paralleling a sufficient number of tubes to render the average characteristics reproducible to within the desired tolerance and probability requirements. In this way we hoped to assure the similarity between the several amplifiers by statistical means. Extensive measurements of the characteristics of several tube types including the 6AS6, 6BA6, 6AU6, and 6BE6, were made. Variations between tubes of the same type were found to be too great to permit the use of the statistical approach. It was found, for example, that 10 tubes in parallel could not be expected to give a gain characteristic predictable to 5%. Even with considerable degeneration of the tube charactertistics, tube variations proved too great to permit the use of the statistical approach.

Another approach to the problem of obtaining several multipliers of closely similar characteristics is to use the one multiplier time shared among the several roles. Fig. 1 presents schematically the manner in which one multiplier might be used in the conversion of drag components to velocity components by coordinated switching input and output of the control amplifier. This system possesses special problems in connection with our task because it will be remembered that two successive amplifications are required in the conversion of V squared to constant value represented by K in Fig. 1. Since the multiplier is time shared, it is necessary to provide a memory circuit which stores the magnitude of V in order to make it available for the subsequent reduction of V to K. The complexity of this storage or memory element represents the principle disadvantage of this approach. However, if the commutation process takes place at a rather high rate compared to the requisite response of the computation system, a simple RC time constant would probably suffice in the memory role.

It was during the examination of the commutation problems involved in the time sharing system which we have just described that we hit upon a more appealing technique which effects the required multiplications by the use of diode ring modulators and simple averaging filters. The multiplying portions of the circuit are entirely passive and the gain factor varies in the range from 0 to 1 in accord with the controlled length of rectangular pulses which activate the switching over all of the modulators. Resolving circuits employing these modulators have been built and have operated satisfactorily during the period subsequent to that covered by this report and the details of the diode modulator circuits are therefore deferred until the next report.

TIME SHARED MULTIPLIER

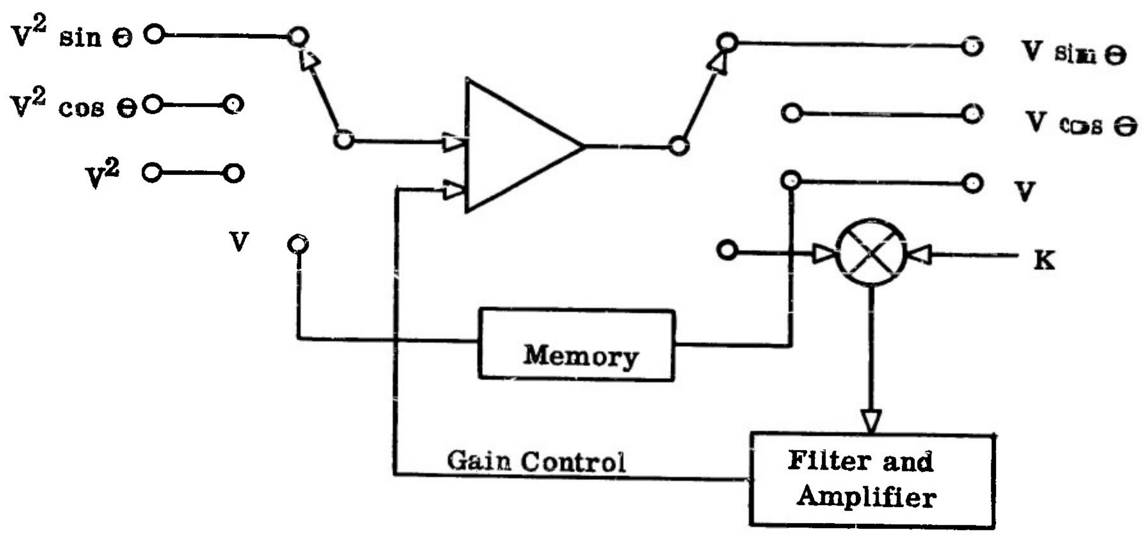

FIG. 1

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